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Analysis of Low NOx Operation of Two Pulverized-Coal Fired Utility Boilers

KVB, Inc., Irvine, CA

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ANALYSIS OF LOW NO_x OPERATION OF TWO PULVERIZED-COAL FIRED UTILITY BOILERS

by

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ABSTRACT

The operation of two pulverized coal-fired utility boilers subject to the 1971 New Source Performance Standard was reviewed to determine if other boilers could adopt a similar mode of operation in the interest of affecting a NO_x reduction. These two boilers had been identified as low NO_x emission sources under a previous study.

It was determined that reburnering, burner modification, or optimization of the overfire air system of existing Foster Wheeler boilers offered the potential to affect a significant NO_x reduction. It was also determined that existing Babcock & Wilcox boilers would probably not be responsive to further combustion modifications.

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SECTION 1.0

BACKGROUND AND OBJECTIVE

KVB, under Work Assignment No. 7, analyzed the long-term NO* emissions from nine pulverized coal-fired utility boilers (Ref. 1-1). The purpose of that assignment was to determine the degree to which these boilers (which were subject to the 1971 New Source Performance Standard-NSPS) could comply with the NO_x provisions of the 1978 NSPS.

A key finding of that study was that two of these nine boilers appeared to be very low NO emission sources. These boilers were:

Iowa Power & Light, Council Bluffs Station, Unit 3

Public Service Co. of New Mexico, San Juan Station, Unit 1†

As noted in Figures 1-1 and 1-2 (taken from Ref. 1-1) the NO probability distributions for these units confirms their being classified as low emission sources. Indeed, the hourly-averaged NO emission measured for Council Bluffs Unit 3 during a 96-day period was always less than the 1978 NSPS for subbituminous coal (0.5 $lb/10^6$ Btu, 215 ng/J). The emissions from San Juan Unit 1 were less than this limitation 96 percent of the time.

The operation of these units was discussed with the appropriate station personnel during site visits. These discussions revealed that both units are being operated at a low combustion air flow in conjunction with

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*The continuous emission monitors installed on these nine boilers (and probably most others) were measuring NO only and not NO_x ($NO + NO_2$). The emissions measured during the performance test by EPA Method 7 is total NO_x.

†This unit was designed to comply with the more stringent State of New Mexico NO_x limitation and not the 1971 NSPS. However, it was included in the previous study.

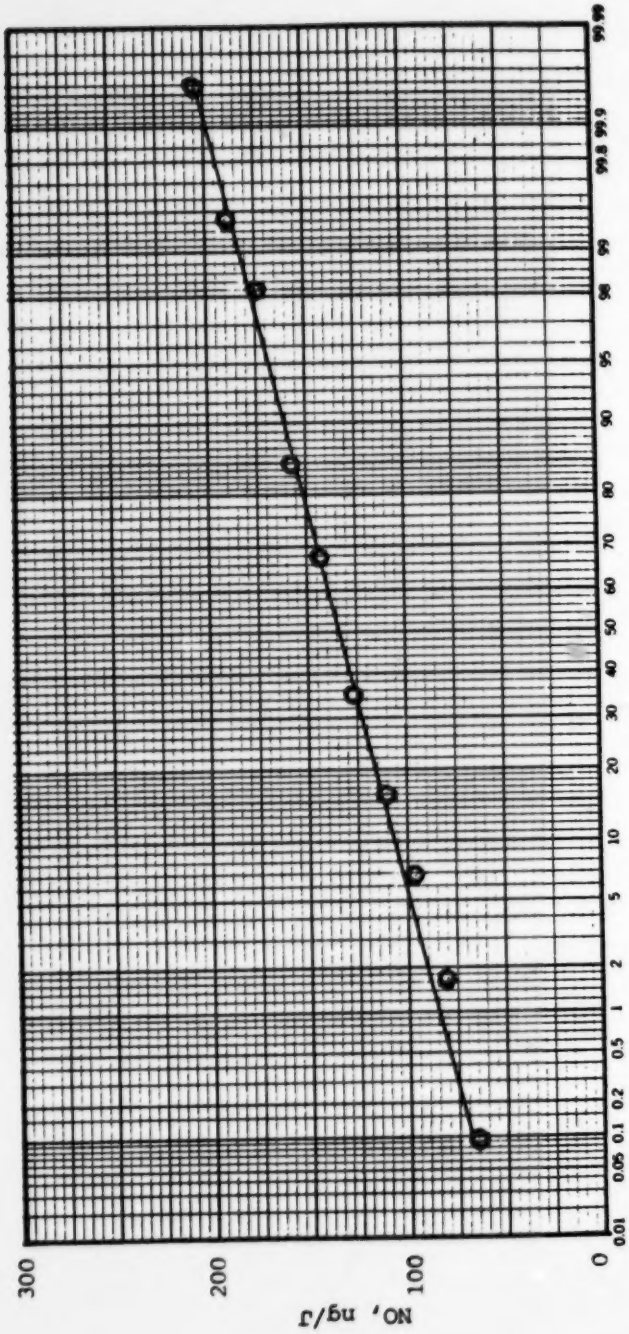


Figure 1-1. Council Bluffs Unit 3 - NO Probability

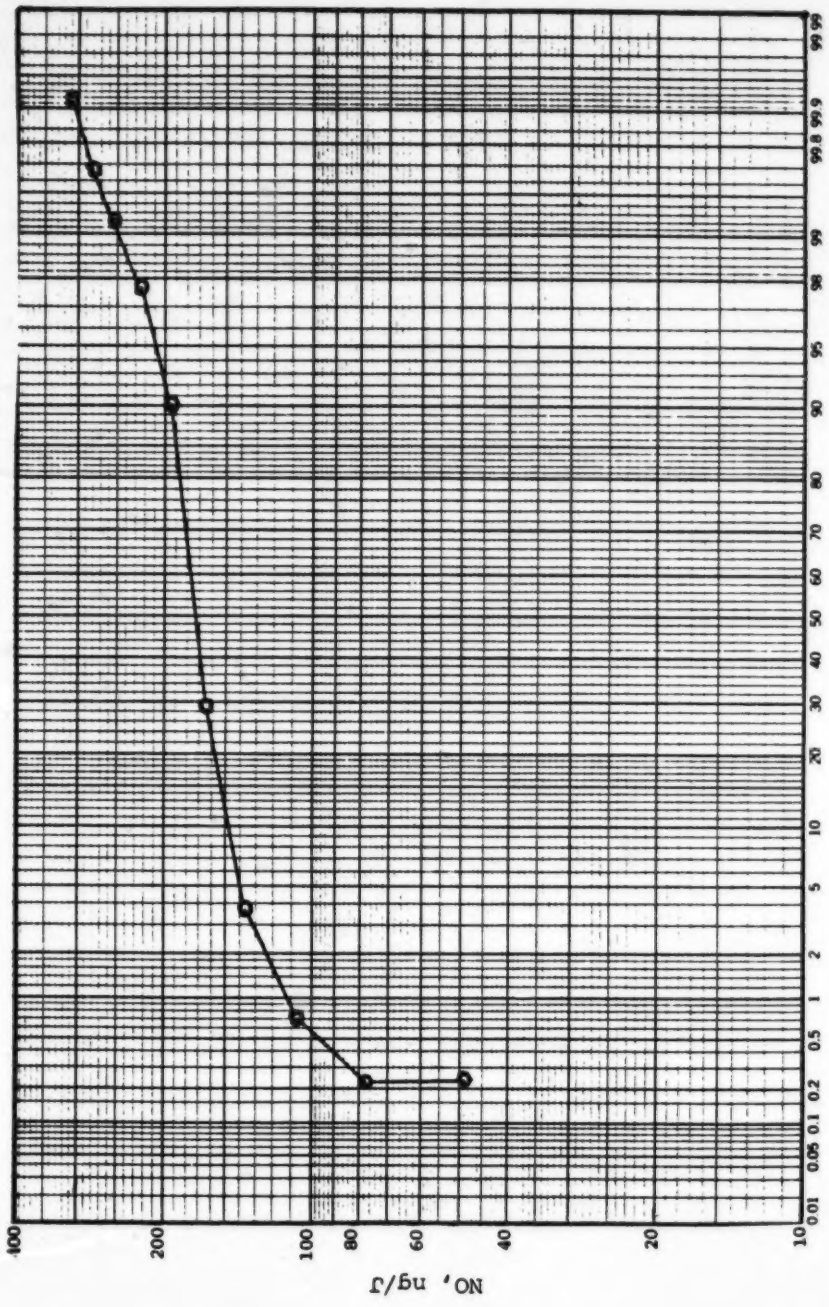


Figure 1-2. San Juan Unit 1 - NO Probability

permanently installed carbon monoxide analyzers. The reason for this operation, however, was different, i.e.:

Council Bluffs 3 - induced draft fan limitation

San Juan 1 - more stringent State of New Mexico NO_x limitation (0.45 lb/10^6 Btu, 194 ng/J)

The objective of the present work assignment is to perform a more detailed analysis of the operation of Council Bluffs 3 and San Juan 1 for the purpose of assessing whether similar modes of operation could be adopted by other pulverized coal-fired utility boilers. It was planned to have the respective boiler manufacturers perform the assessment, i.e., Babcock & Wilcox (Council Bluffs 3) and Foster Wheeler (San Juan 1). However, Foster Wheeler's proposed period of performance could not be accommodated within the work assignment schedule. Therefore, the assessment of Foster Wheeler units was performed by KVB.

SECTION 2.0

UNIT CHARACTERISTICS

2.1 COUNCIL BLUFFS UNIT 3

Site visits were made on September 11, 1981 and June 8, 1982 to discuss boiler operation with Mr. Jim Woodworth, Results Engineer, and other station personnel. (The former visit was in support of Work Assignment No. 7.)

Boiler Design

- Boiler manufacturer is Babcock & Wilcox.
- Opposed face-fired with 56 dual register burners:
  4 rows of 8 burners each on front face
  3 rows of 8 burners each on rear face
- Compartmented windbox.
- Furnace heat release rate is 10,500 Btu/hr-ft^3 at rated capacity.
- Wyoming subbituminous coal.
- Generator rated at 720 MWe gross.

Operational Items

- O_2 Operation: The boiler had been induced draft fan limited at high load. As a result, careful attention is paid to maintaining the operating O_2 at low levels both because of the ID fan limitation and also in the interest of fuel efficiency. The boiler operators are provided with a CO monitor so that minimum air operation can be implemented. The monitor is measuring CO in the stack. In addition, an O_2 trim control is provided using permanently installed probes in the economizer outlet. Typically, the O_2 is 2.5-3 percent at high load and ~6 percent at 40 percent load.
- Heat Rate: The heat rate, based on design specifications, is 9,981 Btu/kWh gross. The operating heat rate is computed and printed on an hourly, daily and monthly averaged basis.

- Steam Temperature: The boiler has experienced no problems in maintaining the design steam temperatures of 1,000/1,000°F superheat/reheat (811 K). Primary superheat area had to be removed as the boiler was too "hot." Spraying is required at nearly all loads.

- Burner Operation: The utility had performed an extensive program to balance the O_2 across the boiler. As a result, all burner registers have been set at:

  Inner Registers - 100 percent open
  Spin Vanes - 20-30 percent open
  Outer Registers - 30-40 percent open

  These register settings are not changed with load.

- Slagging/Fouling: The utility has found that operation at too low an O_2 at high load can cause a slag bridge to form across the superheater tubes. Low load night-time operation in conjunction with sootblowing usually dislodges the slag.

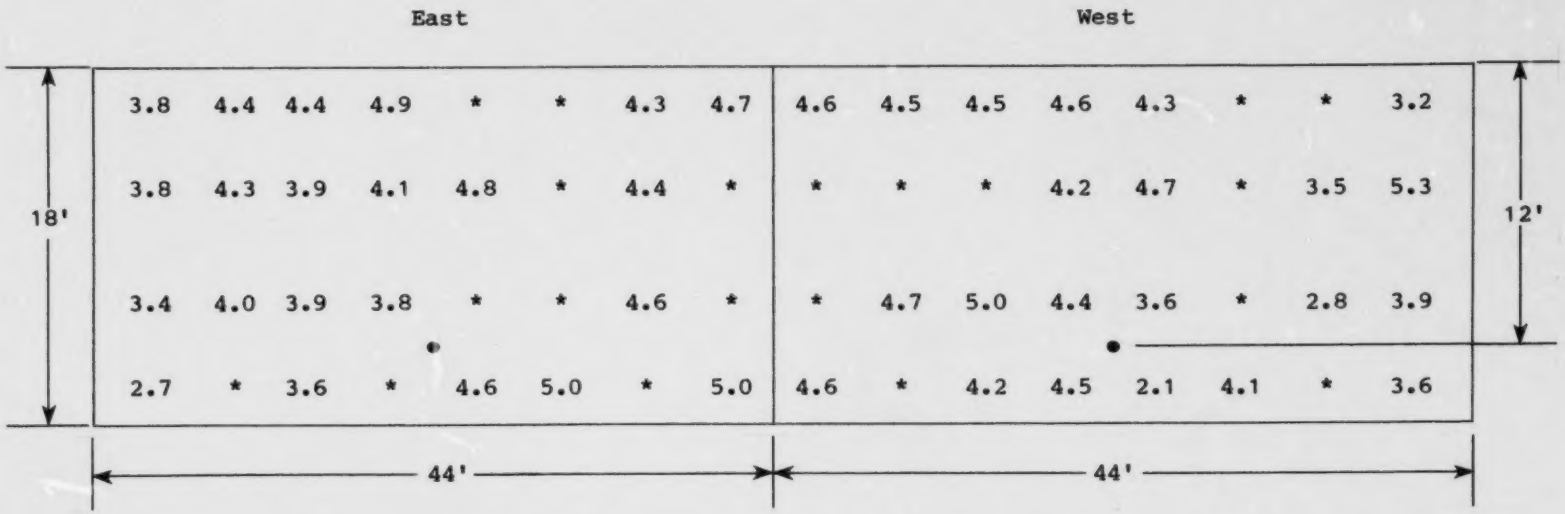
- Unit Load Limitation: Any air heater pluggage or precipitator leakage aggravates the ID fan limitation. On occasion this has limited the boiler to approximately 700 MWe gross.

- Ash Carbon Characteristics: The flyash is sold to cement kiln operators who periodically test for flyash carbon content. The average carbon content measured was 0.4 percent with a maximum of 1.4 percent.

- Tube Wastage: None determined.

- NO Emissions Excursions: The analysis of the emissions data indicated no periods of excess emissions.

The boiler controls were supplied by Fischer and has provision for O_2 trim using two probes, one in each economizer section. These probes are averaged for the O_2 system. Babcock & Wilcox, for their test purposes, installed 32 fixed probes in each economizer duct (64 total). Once every other week the plant reads these probes using a portable Teledyne O_2 analyzer to check on flow stratification. Balancing of the O_2 concentration across the ducts is performed to avoid low O_2 "pockets" and reduce slagging tendencies. Figure 2-1 shows the results of a typical O_2 survey in each duct. Of note is



* Plugged

• O_2 probe for trim system (20' downstream of grid)

Date: 5-21-82

Load: 680 MW

East Duct Average: 4.2

Control Room: 3.8

West Duct Average: 4.1

Control Room: 3.6

Overall Duct Average: 4.15

Control Room: 3.7

Figure 2-1. Council Bluffs Unit 3 O_2 Survey

the low O_2 measured at the bottom of the west duct. Presumably, this value can be "back tracked" to an individual burner which could then be adjusted to raise its air flow.

The in-situ CO analyzer was an add-on to an existing CEM package installed in the stack. The measured CO is available to the operators on a cathode ray tube display as well as being printed. A CO level of up to 30-40 ppm is allowed. The utility is considering integrating the CO signal into the boiler air controls.

At the time of the visit to the control room on June 8, 1982, the O_2 in one duct, as measured by the O_2 trim probe, was significantly lower than the other duct. (One O_2 is displayed on a CRT and the other is printed.) At the superheater level Mr. Woodworth saw slag globules starting to form on the tubes. Mr. Woodworth then observed the burners and indicated that some of the outer registers should be opened to balance O_2 across the unit. Mr. Woodworth commented that without this attention the boiler could slag up in a day and would require shutting down for slag removal.

The plant had been visited previously on September 11, 1981, as part of Work Assignment No. 7. At that time the unit was induced draft fan limited at high load. Subsequently, the fan was reworked and the limitation removed. Initially, the unit was being run at a higher O_2 -- 3.8 to 4 percent vs. 2.5 to 3 percent at the time of the second visit. The reason for the higher O_2 operation is that they were using an "old" coal which presumably had lost some volatile matter (coal analysis not obtained). This has caused some degradation in heat rate but has reduced slagging tendency. The higher O_2 has also increased the NO level, i.e., at 640 MWe gross the CEM is measuring 0.39 lb/10^6 Btu (168 ng/J). The KVB analysis of the unit (Ref. 1-1) at the lower O_2 indicated that the NO was 0.32 lb/10^6 Btu (138 ng/J) at this load or a 22 percent NO increase due to higher O_2 operation. The plant intends to gradually reduce O_2 to restore the heat rate and lower NO.

It appears that the O_2 trim system is not being run in an automatic mode. Rather, the operator manually biases the air controls as load changes.

2.2 SAN JUAN UNIT 1

Site visits were made on September 10, 1981 and June 7, 1982 to discuss unit operations. The former visit was made in support of Work Assignment No. 7.

On September 10, 1981, a meeting was held with Mr. Hank Taylor, Environmental Coordinator, and Mr. Joseph Gonzales, Operations Supervisor. This unit is subject to the more stringent NO_x regulations imposed by the State of New Mexico (0.45 lb/10^6 Btu - 194 ng/J) and unit operation is dictated by these regulations.

Boiler Design

- Boiler manufacturer is Foster Wheeler.
- Burner design is dual register controlled flow/split flame variable velocity (CF/SV) with overfire air ports above top burner row.*
- Front-face fired with 16 burners in 4 x 4 pattern.
- Furnace heat release rate is 11,640 Btu/hr-ft^3 at 95 percent of maximum continuous rating.
- New Mexico subbituminous coal.
- Generator rated at 360 MWe gross.

Operation Items

- O_2 Operation: The furnace O_2 is maintained as low as practical to limit NO emissions. The control room is equipped with a strip-chart output of CO and a cathode ray tube presentation of O_2 and NO. If the NO approaches the alarm level then the operator will reduce O_2 consistent with maintaining the CO at less than 200 ppm. The CO measurement is a composite based on multi-point sampling in the economizer section.
- Heat Rate: The operating heat rate is approximately 10,000 Btu/kWh.
- Steam Temperature: The unit is able to maintain design temperatures of 1005/1005°F (814/814 K) (SH/RH) without any problem.

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*See Section 2.2.. for a discussion on burner development.

- OFA Operation: The overfire air ports, located above the top burner row, are closed and not used.

- Burner Operation: The burner register settings are not adjusted with unit load. The settings were previously determined during a test program.

- Slagging/Fouling: Occasionally a clinker forms in the convective section, however, the unit has never been shut-down for clinker bridging in the nose region.

- Unit Availability: The only availability problem has been due to mill operation.

- Ash Carbon Characteristics: Flyash samples analyzed during 1976 and 1979 showed carbon contents of 1.51, 1.22, 1.09, and 0.37 percent.

- Tube Erosion: High gas velocity, due to clinker formation in the convective section, has caused a minor amount of tube wastage.

- NO Emissions Excursions: Only occur during upset conditions, e.g., unit breakdown or mill startup.

On June 7, 1982, a second visit was made to Public Service Company of New Mexico to further discuss operation of San Juan Unit 1. Discussions were held with Mr. Hank Taylor, Environmental Coordinator, and Mr. Doug Lorenz, Instrument Foreman.

The boiler control is a Bailey Meter Co., Model 762 Burner Management System, and was furnished with O_2 trim. There are two O_2 probes in each economizer duct (four total) and trim can be operated using either probe in either duct.

The CO monitor system is an add-on and is not tied into the control system. There are four probes in each economizer duct of two different lengths. All eight probes are connected together to produce one reading. An Anarad CO monitor drives a strip-chart recorder mounted in the control room.

NO is displayed on a cathode ray tube (CRT) and is set to alarm at 330 ppm (approximately 0.44 lb/10^6 Btu). This measurement is made by an

extractive CEM package located on the stack after the wet SO_x scrubber. In the event of an alarm, the operator will:

1. Put air controls in manual.
2. Close down on fan dampers in a small step.
3. Recheck NO after the unit stabilizes.
4. Repeat steps 2 and 3 until either:
   a. NO is reduced below alarm level, or
   b. CO reaches 200 ppm

If 4a. happens first, then air controls are returned to automatic. If 4b. happens first, then this condition [NO > 0.45 lb/10^6 Btu (194 ng/J), CO ≈ 200 ppm] is accepted and periods of excess NO emissions are experienced.

Other items of interest are:

1. As is usual, air leads fuel with increasing load and air trails fuel with decreasing load.
2. O_2 trim is in automatic with three or four mills operating (for loads greater than approximately 50 percent).
3. Coal quality can change on a daily basis - sometimes full load can be obtained on three mills, sometimes four mills are required.
4. The plant is investigating the incorporation of the CO measurement into air controls.

2.2.1 San Juan Unit 1 Burner Development Program

The burners presently installed in San Juan Unit 1 are the result of an extensive development program undertaken by Foster Wheeler. Table 2-1 summarizes the pertinent features of the burner types which will be discussed below. (This summary and the subsequent discussion are based on Ref. 2-1.)

Tests conducted on the Intervane burner (Figure 2-2) previously installed in San Juan Unit 1 are shown in Figure 2-3. As noted, the high-turbulence Intervane (IV) burner was emitting NO_x at a rate in excess of 1 lb/10^6 Btu (430 ng/J) with the overfire air ports closed. With the ports open the NO_x level decreased to 0.63 lb/10^6 Btu (271 ng/J). Thus, the use of the

TABLE 2-1. PERTINENT FEATURES OF FOSTER WHEELER BURNERS

Burner Designation	Pertinent Features
Intervane (IV)	Single register; high turbulence; annular coal nozzle; installed on units sold in 1971-1976.
Controlled Flow (CF)	Dual, parallel registers; annular coal nozzle; installed on units sold in 1976-1978.
Controlled Flow/ Split Flame (CF/SF)	Dual, series registers; annular coal nozzle with flow splitters; local $\emptyset \approx 0.7$ without OFA.
Controlled Flow/ Split Flame Variable Velocity (CF/SV)	As in CF/SF with control of primary air/coal stream velocity.

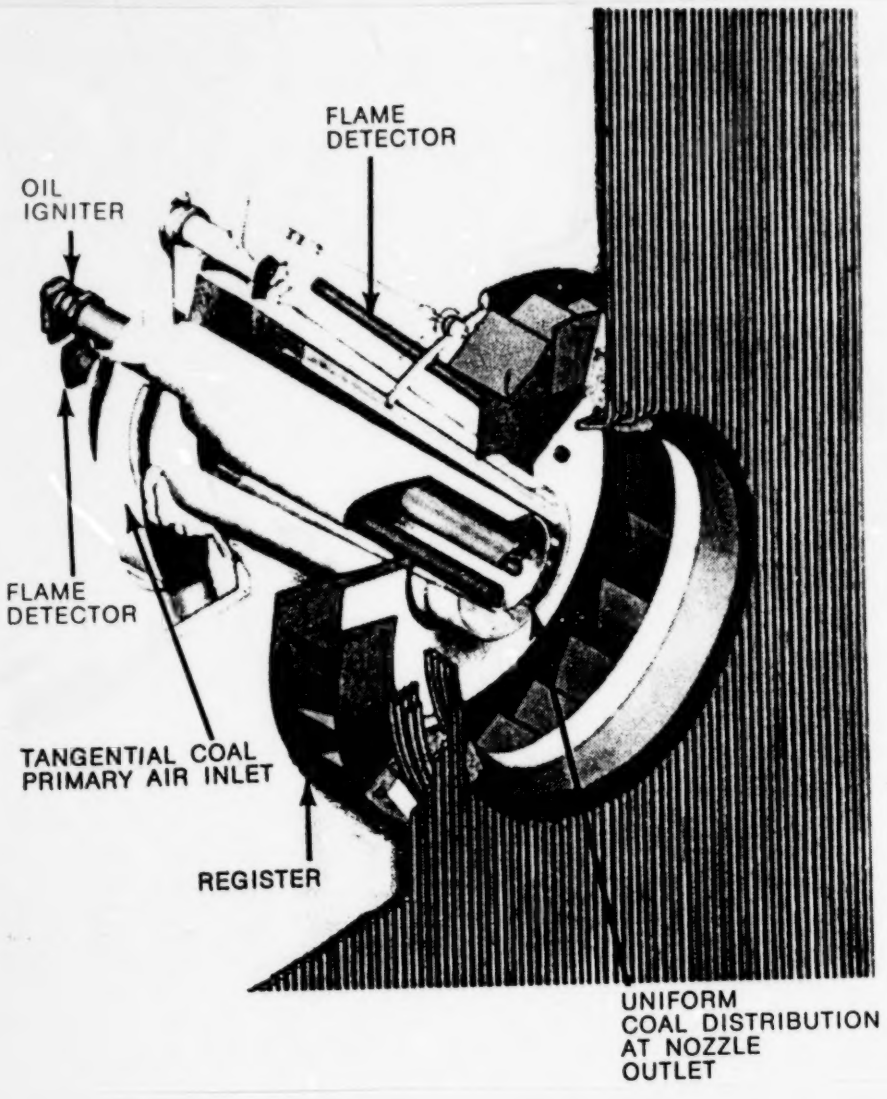

Figure 2-2. High Turbulence Intervane Burner

IV = Intervane Burner
CF/SV = Controlled Flow/Split Flame Variable Velocity Burner

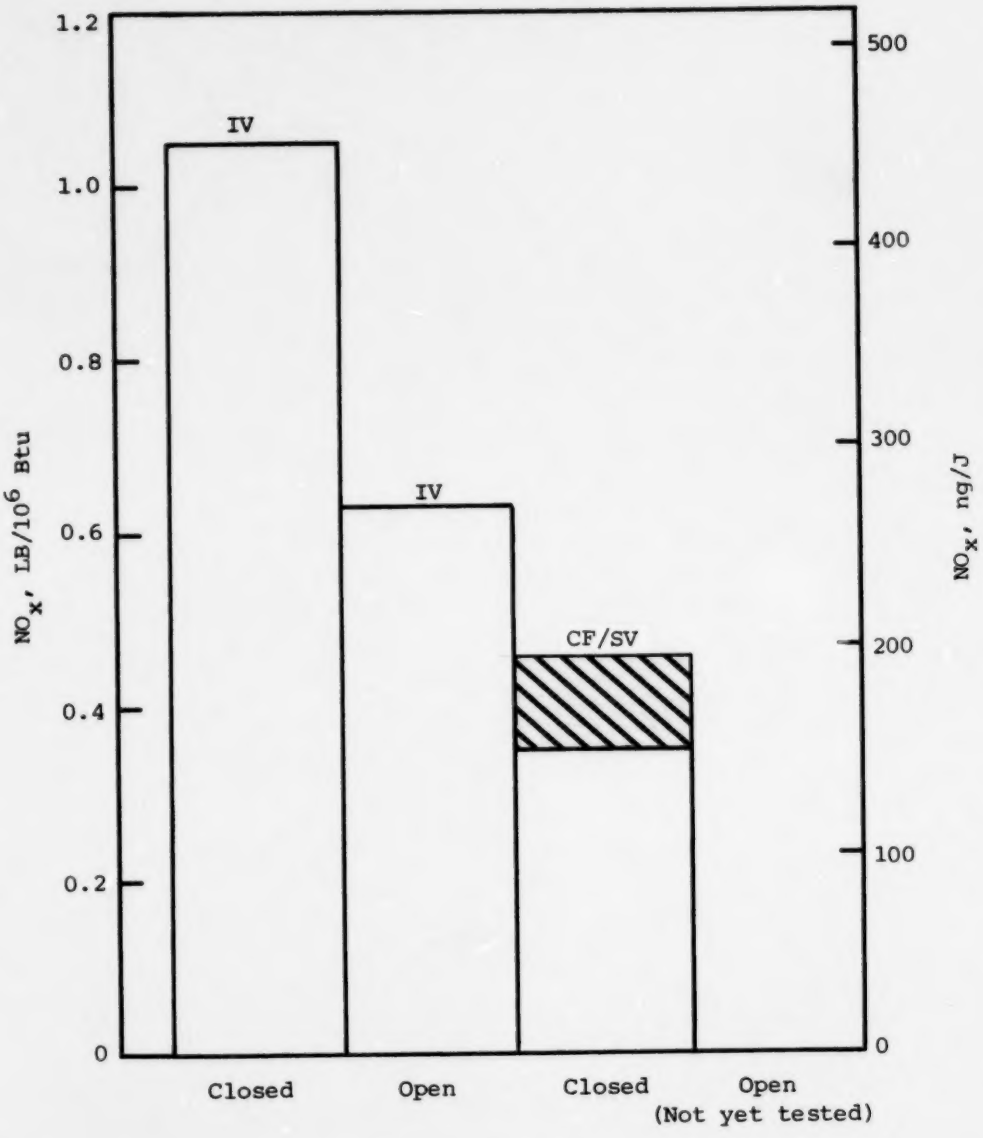

Figure 2-3. Low NO_x Burner Comparison

overfire air ports reduced the NO_x emissions by 40 percent. The NO_x level, however, was in excess of the State of New Mexico limitation of 0.45 $lb/10^6$ Btu (194 ng/J).

The controlled flow/split flame variable velocity (CF/SV) burner (Figure 2-4) is presently installed in San Juan Unit 1. (Also shown in Figure 2-4 is the controlled flow (CF) burner which is also a dual register design.) This burner produces an internal staging effect by separating the coal stream into four discrete streams. It is claimed that a local fuel-rich condition ($\phi \approx 0.7$) is produced by splitting the coal stream. This condition ceases within two throat diameters of the burner as the four discrete streams gradually merge.

This burner has achieved a NO_x level of 0.35 $lb/10^6$ Btu (151 ng/J) with the overfire air ports closed during a performance test conducted for the State of New Mexico. Typical day-to-day operation with the overfire air ports closed has produced NO levels in the range of 0.35 to 0.43 $lb/10^6$ Btu (151 to 185 ng/J). These levels represent a reduction of 59 to 67 percent from the IV burner with the overfire air ports closed.

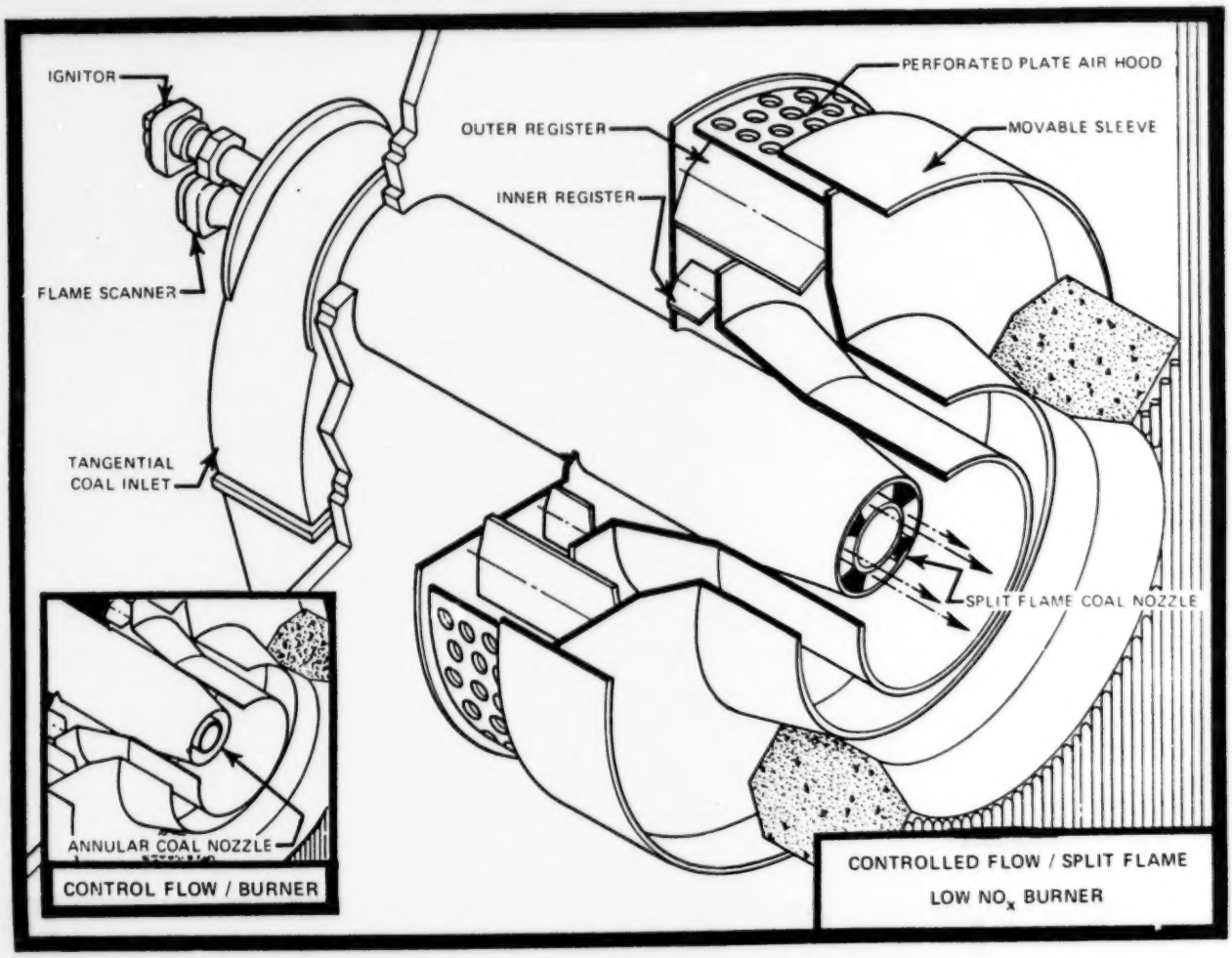

Figure 2-4. Controlled Flow Burners

SECTION 3.0

ASSESSMENT OF BABCOCK & WILCOX NSPS UNITS

This assessment was performed by Babcock & Wilcox. The basis of their work was to use Iowa Power & Light, Council Bluffs Station, Unit 3 as a model of an NSPS unit operating at low excess air. It will be recalled that this unit at one time had an induced draft fan limitation which required careful control of total air flow rate, especially at high load. It was assumed that this mode of operation was responsible for what was perceived to be a low NO_x emission source.

B&W was to then compare their other subbituminous coal-fired 1971 NSPS units with Council Bluffs Unit 3 in order to quantify the potential NO_x reduction resulting from the adoption of Council Bluffs' operating mode. It is to be noted that all B&W pulverized coal-fired utility boilers subject to the 1971 NSPS are equipped with both dual register burners and compartmented windboxes. Therefore, further NO_x reductions would not involve any significant hardware modifications, e.g., burner replacement.

3.1 LOW EXCESS AIR OPERATION OF COUNCIL BLUFF'S UNIT 3*

The Iowa Power & Light Council Bluff Unit 3 was designed to meet an NO_x emission limit of 0.7 lb/10^6 Btu at an expected excess air level of 17 percent at full load. Actual emissions testing after the unit was in operation demonstrated that a level as low as 0.42 lb/10^6 Btu could be reached. This low NO_x level, lower than the 0.5 lb/10^6 Btu regulation contained in the 1978 NSPS, is not unusual for units firing subbituminous coals. Units designed soon after the first NO_x regulations were applied, were fairly conservatively designed since extensive NO_x operating data was only beginning to be collected.

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*This section is based on an analysis prepared by John E. Fairbanks, B&W, Barberton, OH.

Short-term, full-load NO_x testing performed on the subject unit (using a chemiluminescent analyzer) in 1980 produced a level of 0.42 lb/10^6 Btu with only 11.4 percent excess air. The same test series also demonstrated a lower value of 0.38 lb/10^6 Btu at 16 percent excess air and also 0.40 lb/10^6 Btu with 18.9 percent excess air (with one mill out of service). This would seem to indicate that for this particular boiler, the minimum NO_x had been reached and excess air was having very little effect on further reductions. This might not be the case for a more tightly designed unit, however.

The above data would indicate that there was no relationship between NO_x and O_2 (excess air) at full-load conditions. This result would be contrary to other test results (e.g., Ref. 3-1) which showed that a lower O_2 (lower excess air) reduced NO_x emissions. However, it is recognized that only three data points were obtained and that variations in other parameters, e.g., coal properties, could have masked the NO_x vs. O_2 dependency.

Oxygen trim systems for excess air control have been supplied on virtually all B&W boilers for at least the last 25 years. The early systems were not very reliable and were not widely used. With improvements in the O_2 measuring devices the systems have become more dependable and are now used on a continuous basis.

A typical system has two gas sampling probes, one in each duct at the economizer outlet. Occasionally four probes, two in each duct, will be used. The major failing with this system is that the probes are installed with little attention to finding a representative sampling point. Often the probe is located in an area that is much higher or lower than the average O_2 level. It is also possible for the gas stratification in the duct to change as the boiler load changes.

The optimum sampling system would be a multipoint sampling grid installed across the whole width of the ducts. This would assure a representative average at all times. The additional cost for this system would be small (probably under $10,000) however, it would be a required maintenance item to keep the probes clear and operating. This cost is for the hardware only and does not include installation.

Operating at low excess air levels can cause problems in the combustion zone. All boilers have some degree of air distribution imbalance. The only way to assure even air distribution to all burners is to have a separate windbox for each burner, an expensive solution. The older style of a common windbox for all burners relied on the individual burner registers to distribute the combustion air. The newer style B&W compartmented windbox controls air to separate levels of burners. This significantly improves the air distribution and therefore allows for operation at generally lower excess air.

Despite the improved air distribution there can still be localized pockets of poor air-fuel mixing. Under normal excess air levels there is usually enough air available to compensate. Under very low air levels there may not be enough air available for local deficient zones. This could lead to high CO or unburned carbon and in extreme conditions, although unlikely, could lead to localized tube wastage. A complete multipoint sampling grid and careful testing to measure air flows to individual burners would help to optimize air distribution.

Furnace slagging is also a concern for low excess air operation. While it appears Council Bluffs is not having any significant slagging problems, other units burning the same type of coal have had minor problems. In these cases the slagging was alleviated by slightly raising the excess air. If the slagging is only a light buildup an increased sootblowing schedule may also solve the problem without an operation change.

It is also expected that slagging could develop with lignite and bituminous coals. This would be especially troublesome with a high sulfur bituminous coal due to the corrosion potential of a slag layer remaining on the tubes.

The performance comparison shown in Table 3-1 for Council Bluffs Unit 3 is for full load and 70 percent load. For both loads performance is shown at design excess air and a reduced (5 percent lower) air level. It is important to note that these values are calculated using design parameters, not using test data. Therefore, the magnitude of spray flows (for instance)

TABLE 3-1. IOWA POWER & LIGHT, COUNCIL BLUFFS UNIT 3
CALCULATED PERFORMANCE PARAMETERS

Calculated Performance	Full Load Design Air	Full Load Low Air	70% Load Design Air	70% Load Low Air
Main Steam Flow 10^3 lb/hr	4850	4850	3285	3285
(kg/s)	(611)	(611)	(414)	(414)
Reheat Steam Flow 10^3 lb/hr	4440	4440	3075	3075
(kg/s)	(559)	(559)	(387)	(387)
% Excess Air (Economizer Outlet)	17	12	21	16
Burners in Operation	56	56	56	56
Steam Leaving S.H. °F	1005	1005	1005	1005
(K)	(814)	(814)	(814)	(814)
Steam Leaving R.H. °F	1005	1005	998	980
(K)	(814)	(814)	(810)	(800)
Steam Entering R.H. °F	605	605	570	570
(K)	(592)	(592)	(572)	(572)
Gas Leaving Econ. °F	759	751	684	672
(K)	(677)	(673)	(636)	(629)
Air Leaving A.H. °F	599	604	625	630
(K)	(588)	(591)	(603)	(606)
S.H. Spray lb/hr	50997	43375	21075	16607
(kg/s)	(6.43)	(5.47)	(2.66)	(2.09)
R.H. Spray lb/hr	98496	68445	0	0
(kg/s)	(12.4)	(8.62)	(0)	(0)
Flue Gas Lvg. Econ. 10^3 lb/hr	7192	6921	5273	5021
(kg/s)	(906)	(872)	(664)	(633)
Air Leaving A.H. 10^3 lb/hr	6261	5999	4554	4335
(kg/s)	(789)	(756)	(574)	(546)
Boiler Efficiency %	83.56	83.70	83.50	83.64

may not necessarily represent the actual flows, but the relative difference between spray flows at normal and low excess air conditions should compare to actual operation.

The boiler efficiency for low excess air operation was essentially the same as normal operation (it increased very slightly). Of equal importance is that the desired reheat outlet temperature (1005°F - 814 K) could not be maintained at the low load condition, being almost 10°F (6 K) low at the design air condition and 25°F (14 K) low at the reduced air condition.

In summary, from the brief test data available for the subject unit the low excess air operation did not produce NO_x levels lower than higher air tests. This data is only short-term test data and not day-to-day operation, however.

The unit performance did not suffer from low air operation. The low reheat temperature was the only apparent problem encountered. The change in predicted boiler efficiency shown in Table 3-1 is consistent with the magnitude of the change in excess air. However, the low reheat steam temperatures predicted for reduced load operation would adversely affect the steam turbine efficiency and overall heat rate (Btu/kWh - W/kW). It was estimated that a 10°F (6 K) reduction in reheat steam temperature would require a 0.12 percent increase in fuel consumption to produce the same electrical energy. Similarly, a 25°F (14 K) reduction in reheat steam temperature would require a 0.3 percent increase in fuel consumption.

The equipment necessary for an oxygen trim system is not extensive. Older units would probably benefit from new measuring instruments and all units could benefit from multipoint sampling probes and averaging system.

Low excess air operation should ideally be investigated on a site-specific basis. The obvious problems of slagging, poor combustion (CO and unburned hydrocarbon) and actual performance conditions would have to be investigated.

3.2 CONCLUSIONS

In general terms, it has been the recent experience of Babcock & Wilcox that boilers of contemporary design burning subbituminous coals emit reasonably low NO_x levels. There are twelve subbituminous coal-fired units in operation for which NO_x test data is available. All these units are equipped with dual register burners and a compartmented windbox.

These data are shown in Figure 3-1 in terms of the gross MWe/firing wall. (This variable is discussed in Section 4.1). An analysis of this data indicated that there was no correlation between the parameters, i.e., the entire group of 12 boilers could be represented by the average NO_x of 275 ppm (approximately 0.37 lb/10^6 Btu) with a standard deviation of 66 ppm (0.09 lb/10^6 Btu). Of note is that the emission from Council Bluffs Unit 3 (256 ppm--0.34 lb/10^6 Btu) is statistically not different from the balance of the sample.

This does not mean that low excess air operation might not reduce NO_x on some units. It does indicate that boilers designed for low excess air operation equipped with low NO_x burners and operating with close air control (compartmented windbox) already achieve low NO_x and might actually be running at the lowest practical NO_x for the given equipment (as illustrated by the results obtained for Council Bluffs Unit 3).

Reducing excess air to control NO_x may be more suited to slightly older units. Units designed to attain a NO_x control limit of 0.7 lb/10^6 Btu and that might be operating close to this limit could possibly benefit by this operating change.

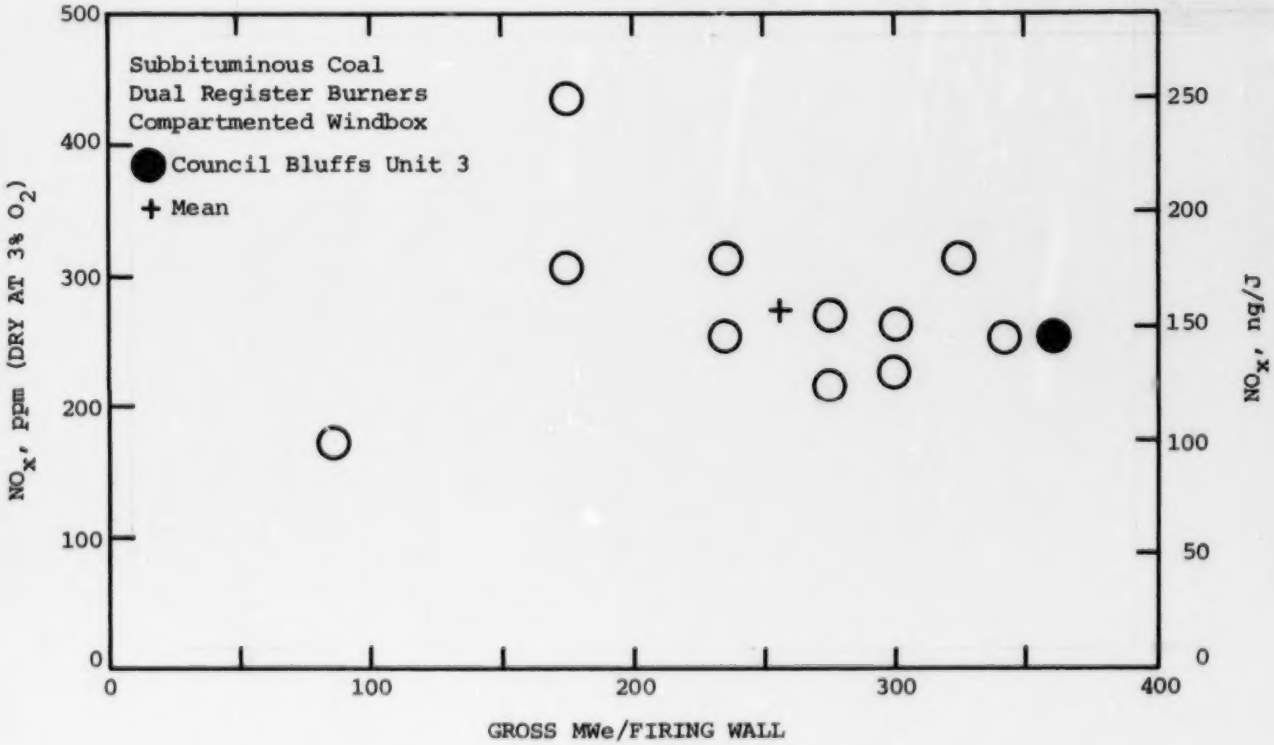

Figure 3-1. Babcock & Wilcox 1971 NSPS Boilers

SECTION 4.0

ASSESSMENT OF FOSTER WHEELER NSPS UNITS

4.1 SURVEY AND CORRELATION OF FOSTER WHEELER NSPS UNITS

The potential NO_x reduction of Foster Wheeler NSPS units is based on using San Juan Unit 1 as a model. As previously discussed, NO_x emissions have been measured on this unit for the following conditions:

1. IV burner without overfire air
2. IV burner with overfire air
3. CF/SV burner without overfire air

The relative NO_x levels for the above conditions could then be used to assess the potential NO_x levels for other Foster Wheeler boilers subject to the 1971 New Source Performance Standard.

A survey was conducted of those utilities operating Foster Wheeler boilers which appeared to be subject to the 1971 NSPS. These contacts were made on the basis of the order dates listed in a Foster Wheeler publication entitled "Central Station Steam Generators - a Partial Listing of Recent Installations." The survey results are presented in Table 4-1. (There are several additional units which have yet to be performance tested.)

As noted, the majority of these units are equipped with the single-register, high-turbulence Intervane (IV) burner and are operating with overfire air (OFA). (The prime exception is San Juan Unit 1 which has been discussed.) The performance NO_x values* for this category are plotted in Figure 4-1 in terms of the gross megawatts per firing wall. For front-wall units this parameter is numerically equal to the generator's rated gross output, while for opposed-wall firing it is one half of the generator's rated gross output. This type of correlation was performed by Exxon for pre-1971 NSPS pulverized coal-fired boilers (Ref. 3-1).

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*That value of NO_x measured during the performance test required by the 1971 NSPS using EPA Method 7.

TABLE 4-1. SUMMARY OF FOSTER WHEELER PULVERIZED COAL-FIRED NSPS UTILITY BOILERS

Test	Utility	Station	Unit	Gross MWe	Firing Mode[1]	No. of Burners	Burner Type[2]	Overfire Air	Coal Type[3]	Performance lb/10^6 Btu	NO_x ng/J
1A.	Public Service Co. New Mexico	San Juan	1	360	1	16	IV	No	Sub.	1.05	452
1B.							IV	Yes		0.63	271
1C.							CF/SV	No		0.35	151
2.	Omaha Public Power District	Nebraska City	1	575	2	28	IV	Yes[4]	Sub.	0.479	206
3.	Proprietary	--	--	114	1	8	IV	Yes	Sub.	0.699	301
4.	Portland General Electric	Boardman	1	530	2	32	CF/SV	Yes	Sub.	0.57[5]	245
5.	Nebraska Public Power District	Gentlemen	1	650	2	32	IV	Yes	Sub.	0.354	152
6.	Proprietary	--	--	500	2	24	IV	Yes	Sub.	0.518	223
7.	Proprietary	--	--	534	2	24	CF	Yes	Sub.	0.465[5]	200
8.	Northern Indiana Public Service	Schahfer	15	511	2	24	IV	Yes	Sub.	0.45	194
9.	Iowa Public Service	Neal	4	630	2	28	IV	Yes	Sub.	0.345	148
10.	Allegheny Power Service	Pleasants	1	660	2	24	IV	Yes	Bit.	0.61	262
11.	Allegheny Power Service	Pleasants	2	660	2	24	IV	Yes	Bit.	0.61	262
12.	Proprietary	--	--	770	2	48	IV	Yes	Bit.	0.63	271
13.	Proprietary	--	--	860	2	32	IV	Yes	Bit.	0.66	284
14.	Proprietary	--	--	736[6]	2	40	IV	Yes	Bit.	0.43	185

[1] 1 = Front-wall
2 = Opposed-wall

[2] IV = Intervane
CF/SV = Controlled flow/split flame variable velocity
CF = Controlled flow

[3] Sub. = Subbituminous
Bit. = Bituminous

[4] Interstage air

[5] Overfire air closed

[6] Two separate boilers supplying one steam turbine.

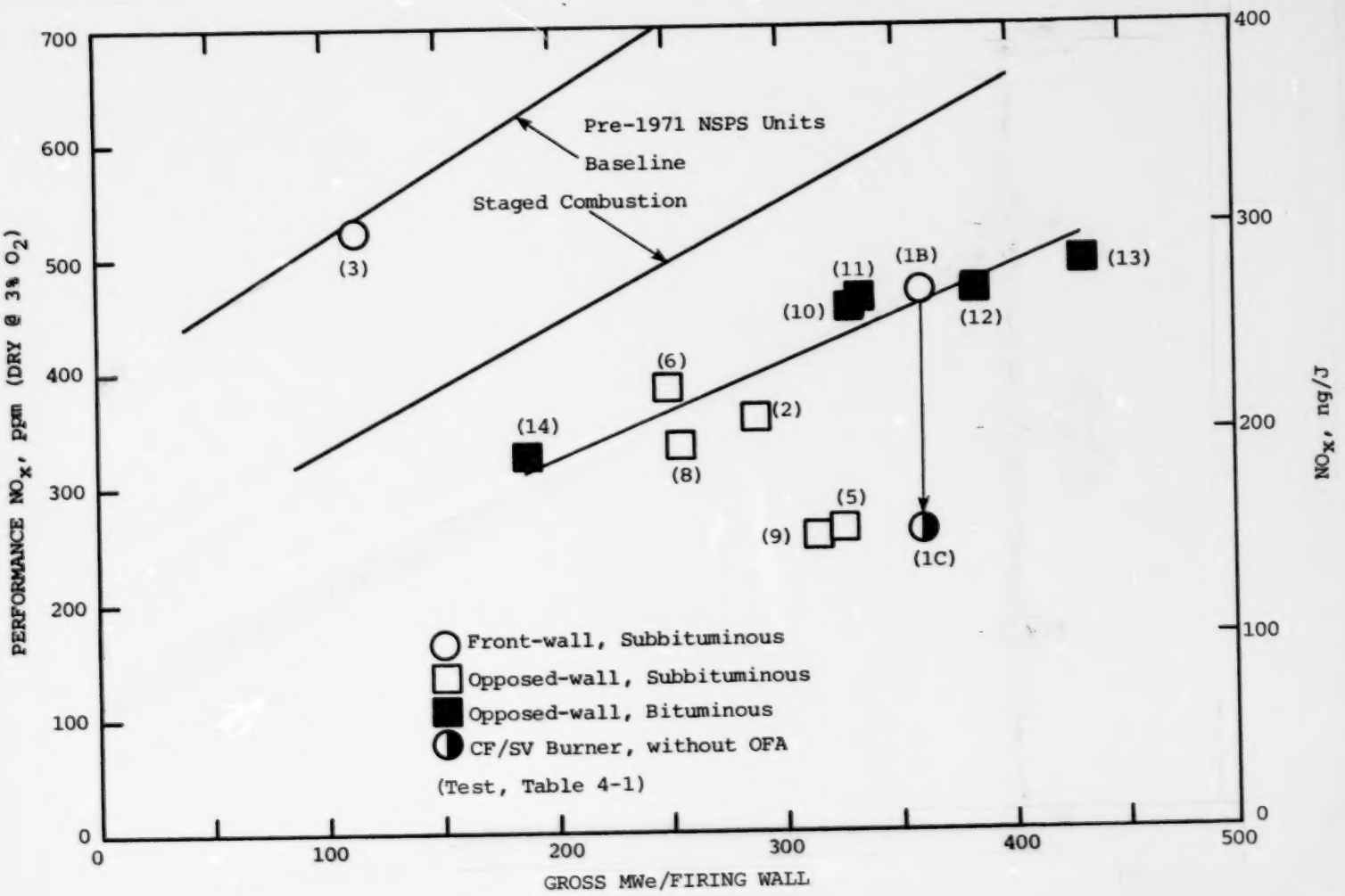

Figure 4-1. Foster Wheeler NSPS Units, Intervane Burners with OFA

Also shown in Figure 4-1 is a linear regression for those Foster Wheeler units (except items 3, 5, and 9) equipped with the IV burner and operating with OFA. This regression was:

$$NO_x \text{ (ppm, dry, @ 3\% } O_2) = 168 + 0.800 \text{ (MWe/wall)}$$
$$(184 < \text{MWe/wall} < 430)$$

with a coefficient of determination (r^2) of 0.85, i.e., a high degree of correlation between NO_x and MWe/wall. In some respects, this parameter is similar in concept to one based on the furnace burner zone liberation rate (Btu/hr-ft^2, W/m^2).

Exxon has reported (Ref. 3-1) on a program involving pre-1971 NSPS pulverized coal-fired utility boilers in order to quantify the effects of long-term low-NO_x operation on fire-side corrosion. This program included boilers of various manufacturers (CE, B&W, FW, and RS), firing modes (front-wall, opposed-wall, corner) using both bituminous and subbituminous coal.

Also shown in Figure 4-1 are regressions based on the Exxon data for both baseline and staged combustion (low NO_x) operation.* The staged combustion was implemented by taking selected burners out of service (BOOS) while maintaining the air flow through these burners. This mode of operation forces the active burners to operate in a fuel-rich condition thereby suppressing both thermal and fuel NO_x production.

These linear regressions yielded (NO_x in ppm @ 3 percent O_2, dry):

Baseline: $NO_x = 390 + 1.265$ (MWe/wall), $r^2 = 0.81$
$(35 < \text{MWe/wall} < 425)$

Staged: $NO_x = 228 + 1.067$ (MWe/wall), $r^2 = 0.85$
$(80.5 < \text{MWe/wall} < 405)$

*The individual data points are not shown in Figure 4-1 in the interest of clarity.

A comparison of the above would indicate that staged combustion of pre-1971 NSPS boilers lowers the NO_x levels by 27 to 38 percent.

As previously noted, the 1971 NSPS Foster Wheeler boilers shown in Figure 4-1 are operating with overfire air -- an operating configuration which will achieve a staged combustion condition. Over the range in gross MWe/firing wall investigated the Foster Wheeler 1971 NSPS units with OFA showed a 25 percent lower NO_x than the pre-1971 NSPS units with BOOS. A portion of this difference may be attributed to more generous furnace dimensions for the NSPS units, i.e., a lower volumetric heat release rate (Btu/hr-ft^3, W/m^3) and a lower burner zone liberation rate (Btu/hr-ft^2, W/m^2).

The lower NO_x for Foster Wheeler Tests 5 and 9 deserve special attention. Both of these units had apparently failed the performance test required by the 1971 NSPS. As a result, the utility and/or Foster Wheeler had instituted a program to reduce the emissions to an acceptable level. Both utilities were contacted to determine the details of the test program in terms of operational and/or hardware modifications. This information is of significant importance to this work assignment since it could quantify the full-scale effectiveness of other NO_x controls. The utility's responses are contained in Sections 4.2 and 4.3.

The high emissions for Test 3 were discussed with the utility. There is no clear explanation for these high emissions and the utility has no plans to perform an emissions reduction program.

4.2 NO_x REDUCTION PROGRAM FOR TEST 9

Iowa Public Service, Neal Station, Unit 4 is equipped with 28 Intervane single register burners arranged in seven rows of four burners per row. There are four rows on the front wall and three rows on the near wall, each row being supplied by a pulverizer (seven total).

There are overfire air ports located above the top row of burners on each firing wall. These ports are 25 percent open in the zero position in order to supply a minimum amount of port cooling air. Near maximum overfire air flow occurs when the port is in the 50 percent open position due to the

low windbox-to-furnace pressure differential, i.e., further opening of the overfire air registers does not significantly increase the air flow.

The low-sulfur Western subbituminous is characterized by its high moisture (30 percent) and low nitrogen (0.5 to 0.75 percent) contents.

Method 7 tests conducted prior to the official performance test indicated a NO_x value of approximately 0.6 lb/10^6 Btu (258 ng/J) with all burners-in-service and the overfire air ports 25 percent open (minimum flow for port cooling). This corresponds to a "0" on the OFA positioner. This value is consistent with the linear regression of other Foster Wheeler NSPS units with the IV burner and overfire air.

The official performance test, however, resulted in NO_x in excess of the 1971 NSPS (0.7 lb/10^6 Btu -- 300 ng/J). A post-test examination of the OFA ports revealed substantial ash deposition on the perforated cone member of the ports which reduced the air flow.

The utility then embarked on a very carefully controlled diagnostic program to determine operating effects vs. NO_x emissions, and to determine if the previous high NO_x readings were attributable to any one burner or other equipment problems. Fresh coal was used during this program in order to obtain a more uniform fuel. Measurements were simultaneously performed as follows:

1. At stack with Lear Siegler SM810.
2. At stack with Method 7.
3. At economizer with TECO chemiluminescent.

Various burner-out-of-service (BOOS) patterns were investigated during this program.* With the top (fourth) row BOOS on the front wall and OFA set for maximum flow the NO_x measured (in lb/10^6 Btu) at the above locations were 0.40, 0.345, and 0.36, respectively. It is to be noted that the air flow through the BOOS was just sufficient for cooling purposes.

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*Full-load could be maintained with any six pulverizers in service.

The cognizant regulatory agency accepted the Method 7 results (0.345 lb/10^6 Btu) as evidence of compliance with the 1971 NSPS. In view of the level achieved (<70 percent of standard) the utility was authorized to discontinue NO_x monitoring and they have done so.

It must be recognized that this NO_x level was obtained during a relatively short, carefully controlled test program. It may not be possible to maintain this level on a normal day-to-day basis. Indeed, the in-situ NO_x monitor (prior to its deactivation) indicated that the NO_x at full load ranged from 0.40 to 0.49 lb/10^6 Btu for many operating modes.

In summary, admitting just cooling air through the BOOS in combination with the maximum OFA flow was deemed responsible for a marked NO_x reduction. Apparently, the OFA ports by themselves were not adequate to produce sufficient staging because of the low windbox-to-furnace pressure differential.

The utility did not note any increased slagging or fouling tendencies in the BOOS configuration. This may be due to the use of boundary air in the furnace, which is intended to maintain an oxidizing atmosphere on the walls.

Finally, the utility assessed that no loss in efficiency was caused by the BOOS operation.

4.3 NO_x REDUCTION PROGRAM FOR TEST 5

Nebraska Public Power District, Gerald Gentlemen Station, Unit 1 is a Foster Wheeler boiler rated at 650 gross MWe. It is opposed face-fired with 32 Intervane burners arranged in a 4 x 4 pattern on each face. It is equipped with eight pulverizers.

The original NO_x performance test conducted during September 1979 was in excess of the NSPS limitation of 0.7 lb/10^6 Btu. The utility contends, however, that the results obtained during this performance test were invalid due to inaccurately calibrated equipment.

The performance test was repeated during September 1982 with calibrated and certified instrumentation. The NO_x obtained during this test was 0.354 lb/10^6 Btu.

Between these two dates the utility made minor adjustments to the overfire air system to regulate the amount of excess air. Apparently, the low NO_x value obtained was due to an increased air flow through the overfire air ports. No hardware modifications were made; rather the dampers in the OFA system were merely adjusted.

4.4 MODIFICATION OF THE INTERVANE TYPE BURNER

Reference 4-1 reported on a program conducted by Arizona Public Service on Units 1, 2, and 3 at the Four Corners Station. Units 1 and 2 were manufactured by Riley Stoker (175 MWe, front-face fired) and Unit 3 by Foster Wheeler (225 MWe, front-face fired). All three are pre-1971 NSPS units but are required by the State of New Mexico to comply with a NO_x emission limit of 0.7 lb/10^6 Btu (which is the same as the 1971 Federal NSPS). The original Riley Stoker burners in Units 1 and 2 were replaced by Foster Wheeler type Intervane burners.

The program consisted of testing various configurations of flow splitters inserted in the annular primary air/coal stream. The purpose of the flow splitters is to separate the coal into four discrete streams thereby delay its mixing and reacting with the secondary air. (This is identical to the purpose of the flow splitters in the Foster Wheeler dual register split flame burner previously discussed.) The flow splitters, in addition to producing localized fuel-rich combustion regions, also serve to increase the primary zone velocity and thereby decrease its mixing with the secondary air stream. (Without the splitters the secondary:primary velocity ratio was 4:1, and this ratio decreased to 2.5:1 with the splitters.)

It was found that the flow splitters produced a 45 percent NO_x reduction on Units 1 and 2 and compliance with the 0.7 lb/10^6 Btu limit. Unit 3, however, was unresponsive to the burner modification. The poor result obtained on Unit 3 was due to the relative placement of the secondary air register and the coal nozzle. In this instance, as shown in Figure 4-2, the secondary air was introduced at the coal nozzle exit such that it destroyed the discrete fuel-rich zones as soon as they were formed.

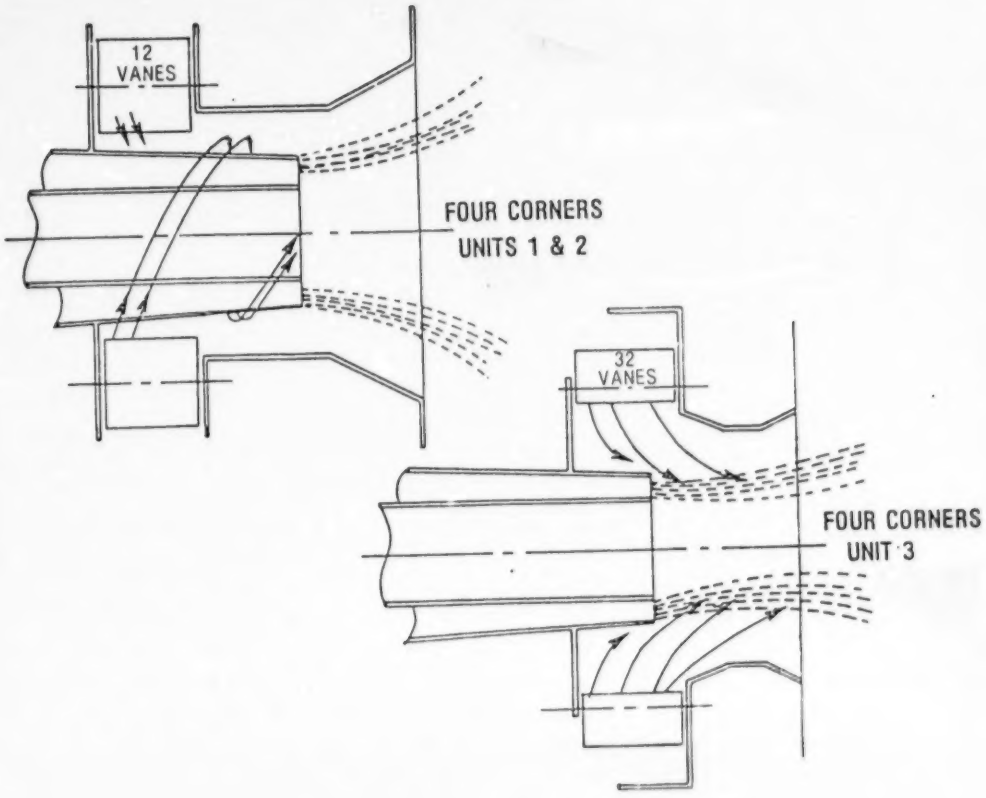

Figure 4-2. Air Register/Coal Nozzle Configurations

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It is recognized that this Intervane burner modification may not produce a similar percentage NO_x reduction on 1971 NSPS units, as these units are basically lower NO_x emission sources. However, this modification may be very useful for a unit operating with a small margin with respect to the 1971 NSPS.

4.5 CONCLUSIONS WITH REGARD TO FOSTER WHEELER UNITS

The foregoing sections have identified several retrofit strategies which have the potential to reduce NO_x emissions on Foster Wheeler units subject to the 1971 NSPS. These strategies include:

1. Burner modification - adding coal splitters to the Intervane burner.

2. Burner replacement - substituting the dual register split flame burner for the single register Intervane burner.

3. Overfire air system optimization - effectively increasing the overfire air flow by operating with selected burners-out-of-service or other means.

The burner modification program was conducted on pre-1971 NSPS units and its effectiveness was very unit-specific. It appears that the standard Intervane burner (Figure 2-2) would not be amenable to this modification since the secondary air register appears to be located at the coal nozzle exit. This configuration is similar to Four Corners Unit 3 (Figure 4-2) which was unresponsive to the coal splitters. However, relocating the secondary air register to a position similar to Four Corners Units 1 and 2 (Figure 4-2) could overcome this deficiency.

It is apparent from the boiler survey and data regression for the Intervane burner that reburnering offers the potential to lower the NO_x emissions from Foster Wheeler NSPS units. The magnitude of the reduction, however, is subject to certain contradictory information, namely the performance NO_x measured with the CF/SV burner at San Juan Unit 1 and Boardman Unit 1. The former presents direct evidence on the effectiveness of the CF/SV burner (without OFA) versus the Intervane burner (with and without overfire air) obtained on the same unit.

The performance NO_x measured at Boardman Unit 1 (0.57 lb/10^6 Btu, 245 ng/J) with the CF/SV burner (without OFA) is comparable to the regression analysis for the Intervane burner (with OFA), as shown in Figure 4-1. This comparison implies that for this particular unit the CF/SV burner has not shown a NO_x level consistent with San Juan Unit 1. Discussions with the utility did not reveal any apparent reason for this situation.

Optimization of the overfire air system has been shown to be an effective NO_x control as discussed in Sections 4.2 and 4.3. In the former situation the overfire air flow was increased by taking out of service the top row of burners on one face. Thus, the air flow through the BOOS supplemented that through the overfire air ports. This approach would be effective for those Foster Wheeler units operating with a low windbox-to-furnace pressure differential. The NO_x reduction achieved by this operating modification was on the order of 50 percent. However, the applicability of BOOS would depend on the capacity of the in-service pulverizers to supply a higher coal flow to the remaining active burners.

SECTION 5.0

CONCLUSIONS

It will be recalled that the objective of this Work Assignment was to assess the potential NO_x reduction for 1971 NSPS boilers manufactured by Babcock & Wilcox and Foster Wheeler. This assessment was to be based on the operation of Council Bluffs Unit 3 (B&W) and San Juan Unit 1 (F.W.).

It was concluded that:

1. B&W 1971 NSPS units would not significantly benefit from the adoption of Council Bluffs Unit 3's mode of operation.

2. Foster Wheeler 1971 NSPS units would benefit from a burner modification, burner replacement or optimization of the overfire air system. The degree of potential NO_x reduction is uncertain.

The first conclusion is based on a comparison between Council Bluffs Unit 3 and other subbituminous coal-fired B&W boilers, which showed no statistical difference in NO_x emission levels measured during the performance test. Thus, the initial perception that Council Bluffs Unit 3 was a significantly low NO_x source is not warranted when compared with other B&W 1971 NSPS units.

Burner modification (adding primary air/coal stream splitters to single register burner), or burner replacement (replacing Intervane burner with controlled flow/split flame variable velocity configuration) or optimization of the overfire air system offers the potential to reduce NO_x emissions on Foster Wheeler 1971 NSPS boilers. Quantification of the effectiveness of these approaches is uncertain due to an apparent unit-specific nature of the results. The effectiveness of burner replacement should become more firmly established as new units with the CF/SV burner are performance tested. Optimization of the overfire air system would probably be most applicable to units with a low windbox-to-furnace pressure differential, or with sufficient pulverizer capacity to operate with burners-out-of-service.

SECTION 6.0

RECOMMENDATIONS

It was originally planned that Work Assignment No. 9 (Contract No. 68-02-3175) would involve implementing low excess air operation on a modern pulverized coal-fired utility boiler for the purpose of quantifying its effect on long-term NO_x emissions and heat rate. The implementation would have been aided by a carbon monoxide (CO) analyzer to assure that the operation was at the lowest practical combustion air flow.

However, it is recommended that Work Assignment No. 9 be restructured to analyze the long-term NO_x emissions and heat rate for units which have already been modified for the specific purpose of reducing their NO_x emissions. This restructuring is based on the following:

1. During the course of this Work Assignment it was determined that operators of certain Foster Wheeler Units had modified the unit's operation in order to reduce NO_x emissions. These programs have been addressed in Sections 4.2 and 4.3. In addition, one other operator had modified the top row of Intervane burners and obtained compliance with the 1971 NSPS. (The utility has been requested to furnish details on the modification.)

2. Exxon, under EPA Contract No. 68-02-2696, had performed extensive modifications on Utah Power & Light, Hunter Station Unit 2 for the purpose of reducing NO_x emissions. This unit was manufactured by Combustion Engineering and is rated at 446 MWe. The coal is classified as a high volatile "B" bituminous coal.

3. Finally, the operation of Council Bluffs Unit 3 had been modified while a poorer quality coal was being burned. This entailed operation at a high air flow (and lower heat rate) which caused an increase in NO_x emissions.

The situations cited above, and others to be identified during Work Assignment No. 9, offer the opportunity to quantify the effect of specific operational and/or hardware changes on long-term NO_x emissions and unit heat

rate. This quantification would be performed with data obtained before and after (approximately 30 days each period) the modification, i.e.:

1. Hourly-averaged continuous emission monitor (CEM) data for NO and O_2.
2. Hourly-averaged unit load in gross MWe.
3. Hourly-averaged unit heat rate (not station heat rate).
4. Periodic coal analyses.
5. CEM certification reports for NO and O_2 analyzers.
6. Specific details on modification.
7. NO_x measured during performance test.

The KVB computer program developed during Work Assignment No. 7 would be used to perform the calculations.

SECTION 7.0

REFERENCES

1-1 Cherry, S. S., "Analysis of Long-Term NO Emissions Data From Pulverized Coal-Fired Utility Boilers: Volume I, Technical Anaysis," EPA-600/7-83-012a, February 1983.

2-1 Vatsky, J., "Development and Field Operation of the Controlled Flow/Split-Flame Burner," Proceedings of the Joint Symposium on Stationary Combustion NO_x Control, October 6-9, Denver, Colorado, IERL-RTP-1083, October 1980.

3-1 Crawford, A. R. et al., "Field Testing: Application of Combustion Modifications to Control NO_x Emissions From Utility Boilers," EPA-650/2-74-066, June 1974.

4-1 Travis, S. R. et al., "Arizona Public Service Company's Burner Modifications for NO_x Control at the Four Corners Power Plant," EPRI NO_x Control Technology Seminar, Denver, Colorado, October 1978.